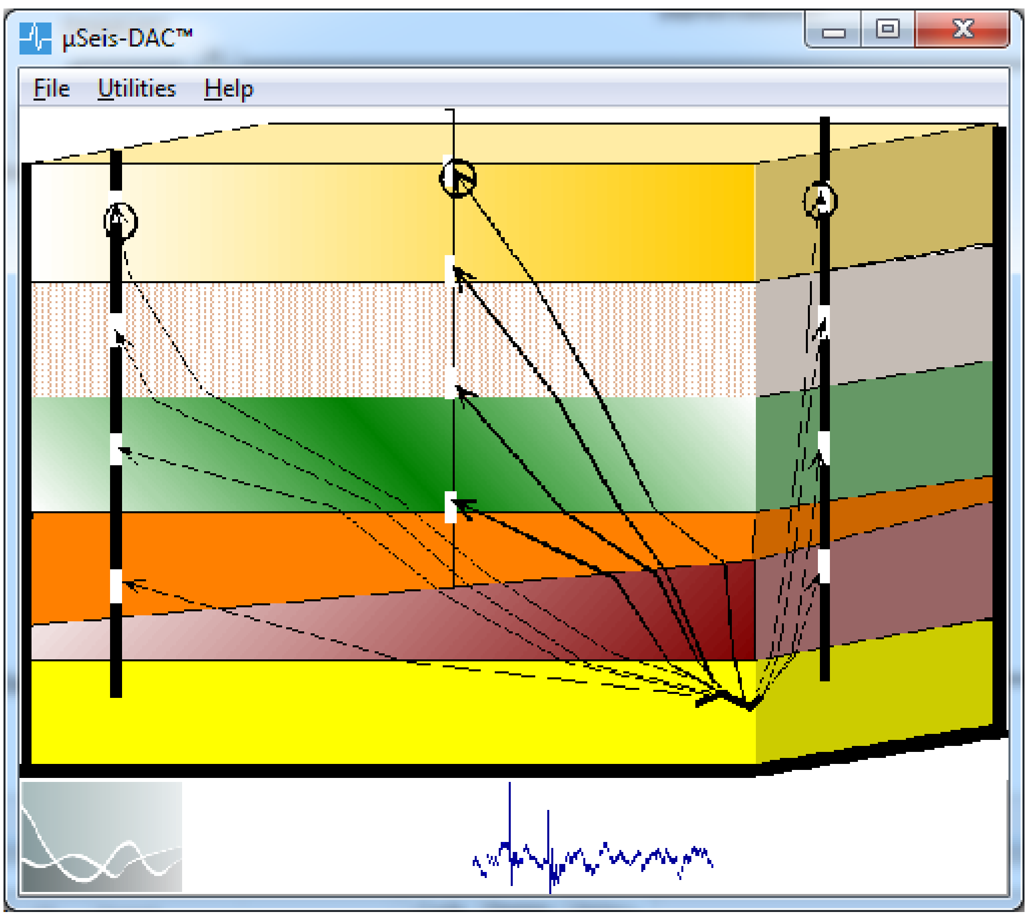
µSEIS-DAC™

User's Reference Manual

BCE
SUB-SURFACE
DIAGNOSTICS



Version 1.0 - June 2011

BCE's mission is to provide our clients around the world with state-of-the-art seismic data acquisition and analysis systems, which allow for better and faster diagnostics of the sub-surface.

The company provides state-of-the-art hardware and software solutions for a wide variety of seismic engineering applications. If necessary, we will customize our products to suit the requirements of our clients even better.

BCE's products and services consist of

- Seismic Data Acquisition and Signal Conditioning Hardware
- Seismic Data Processing Software
- Applied Seismology Consulting Services
- Seismic Data Processing
- Professional Seminars

By publishing this manual we will hopefully provide a better understanding of downhole seismic testing and the role it can play in geotechnical investigations.

Baziw Consulting Engineers Ltd
3943 West 32nd Avenue Vancouver B.C. Canada V6S 1Z4
url: www.bcengineers.com
email: info@bcengineers.com

Table of Contents

List of Figures

Chapter 1 Introduction

1.1 What is µSeis-DAC™?

µSeis-DAC™ is a program that facilitates the data acquisition of Passive (Micro-)Seismic Monitoring (PSM) time series data utilizing sophisticated signal processing and event detection algorithms.

Among engineers there is considerable interest in the real-time identification of "events" within time series data with a low signal to noise ratio (S/N). This is especially true for acoustic emission analysis, which is utilized in the field of PSM. Here an array of seismic receivers are used to acquire acoustic signals to monitor locations where seismic activity is expected: underground excavations, deep open pits and quarries, reservoirs into which fluids are injected or from which fluids are produced, permeable subsurface formations, or sites of large underground explosions.

µSeis-DAC™ is based on the so-called ***SEED™*** (Signal Enhancement and Event Detection) algorithm, which uses real time Bayesian Recursive Estimation (BRE) digital filtering techniques to analyze the raw data. The software is customized for specific job applications and client requirements. For example, typically important system considerations consist of the number of sensors deployed, the type of seismic sensors (accelerometer or geophone), the sensitivity and bandwidth of sensors, and the area under analysis.

µSeis-DAC™ includes the following features:

- Configurable for either geophones or accelerometers.
- Configurable for multi-channel Contact Triggers.
- Configurable for multi-channel Digital Frequency Filter Triggers.
- Configurable for multi-channel *SEED™* Triggers.
- Suitable for P-Wave and S-wave.
- P-wave or S-wave short term average / long term average (STA/LTA) event detection.
- Automated pre-trigger specification.
- Ability to convert acquired PSM data in SEG-2 format.
- Ability to convert acquired PSM data in BCE ASCII triaxial format.
- Display of acquired seismic data with option of applying bandpass, high pass, low pass, and notch digital filters.

1.2 Organization of users manual

The purpose of this manual is to instruct users of ***µSeis-DAC™*** in the use of the product by explaining its structure, taking the user step by step through the program menus, and specifying the use of interactive graphics and I/O routines.

In addition, the manual contains the following items:

- Appendix 1 provides a copy of the paper entitled "Real-time seismic signal enhancement utilizing a hybrid Rao–Blackwellized particle filter and hidden Markov model filter." This paper outlines the mathematical details behind the *SEED™* algorithm.
- Appendix 2 provides a copy of the BCE technical note entitled "Passive (Micro-)Seismic event detection by identifying, quantifying and extracting frequency anomalies within statistically describable background noise". This technical note concisely outlines the *SEED™* algorithm and provides examples of the advantages of the *SEED™* algorithm over standard frequency filtering techniques.
- Appendix 3 provides a copy of the BCE technical note entitled "Relating peak particle velocity and acceleration to moment magnitude in Passive (Micro-)Seismic monitoring". This technical note outlines the relationship between the moment magnitude range of a PSM system and the corresponding peak particle velocity and acceleration. From this relationship the required A/D bit resolution and sensor type requirements can be ascertained for the PSM system.
- Appendix 4 provides the user with a detailed installation procedure for this software. **To ensure that the program will function properly it is important that it is installed correctly.**

Chapter 2 Main Menu

µSeis-DAC™ is a program that facilitates the data acquisition of PSM time series data utilizing sophisticated signal processing and event detection algorithms. The main menu of ***µSeis-DAC™***, as illustrated in Figure 1, has three options:

- *File (to carry out the PSM data acquisition).*
- *Utilities*
- *Help.*

The desired submenu is chosen either by moving the mouse over the desired option and pressing the left hand mouse button, by pressing function <F10> on the keyboard and selecting the desired highlighted option, or by pressing the corresponding menu item letter on the keyboard.

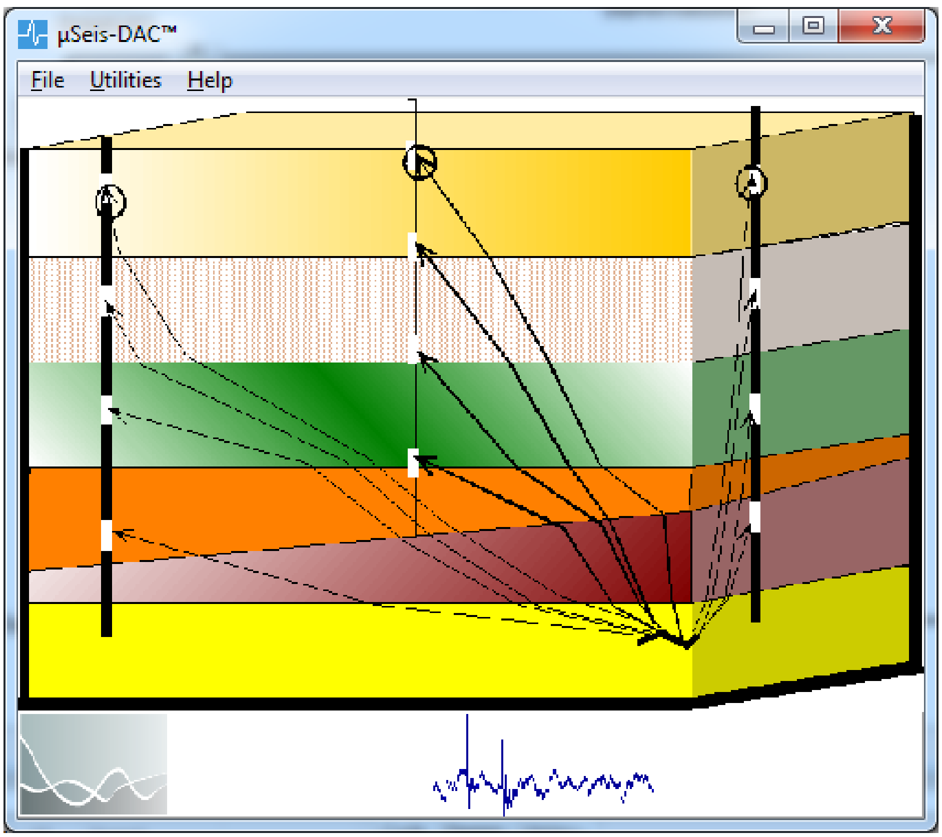


Figure 1: Main Menu in µSeis-DAC™

Chapter 3 Passive (Micro-)Seismic Data Acquisition

The *File* menu option is used to carry out the data acquisition and allows the user to communicate with the signal conditioning board and the analog/digital (A/D) conversion device. As shown in Figure 2, this menu has three tabs for data input:

- *Data File Specification and A/D Parameters*
- *Common Trigger Parameters*
- *Trigger Type Selection*

Once the data has been entered, the tool bar at the top of the screen is used to control the actual data acquisition.

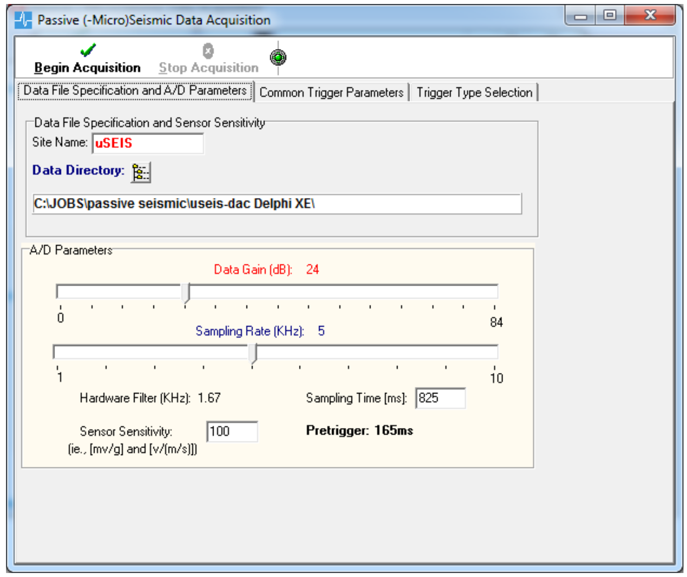


Figure 2: File Menu

3.1 Data File Specification and A/D Parameters

The *Data File Specification and A/D Parameters* tab is illustrated in Figure 2 and the six input parameters required on this tab are as follows:

- **Data File Specification** - the seismic data file naming and saving process is automated within *µSeis-DAC™*. A typical file name for a saved seismic file is outlined and defined as follows:

  uSEIS_11_05_2011 14_18_34_823.aci

  uSEIS - specified by the user in the *Site Name* edit box
  11_05_2011 - day data acquired (i.e., day_month_year)
  14-18-34_823 - **ti**me data acquired (i.e., hour_minute_second_millisecond)
  aci - data saved in ASCII format

  The default data file storage directory is selected by pressing the directory list icon. Figure 3 shows the dialog box that appears when this icon is selected. The user browses the available drives and directories and selects the one most appropriate for seismic data file storage.

- **Data Gain** - the data gain corresponds to the amplitude gain on the recorded data. The Data Gain can be set from 0 to 84 dB in increments of 6 dB.

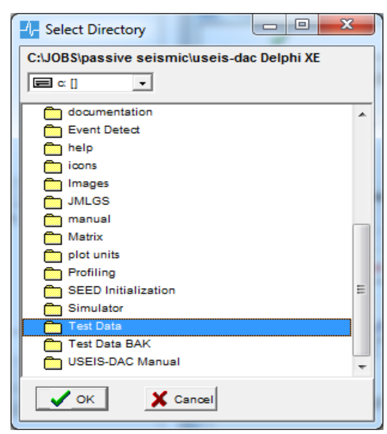


Figure 3: Default Directory Data Dialog Box

- **Sampling Rate** - the sampling rate is specified in KHz and it ranges in values from 1 KHz to 10 KHz with a default value of 5 KHz. The selected sampling rate depends on the CPU capabilities of the computer running the *µSeis-DAC*™ program. If the computer cannot maintain the specified sampling rate for the configured number of channels the error message "*Insufficient CPU speed for Triggering Algorithm!*" is displayed. Whenever this message appears, the user should either decrease the sampling rate, configure fewer channels, or utilize a computer with greater CPU capabilities. However, for the proper operation of this software it is mandatory to disable as many Windows® programs running in the background as possible.
- **Sampling Time** - the sampling time is specified in ms and it corresponds to the total data acquisition time. For optimal data storage and processing, the sampling time should not be much longer than what is required to capture the P-wave and S-wave events for the configured PSM system. There are three fundamental time series measurements obtained from the installed seismic sensor array which allow the investigator to locate an event accurately:
    - the angles of incidence obtained from hodogram or polarization analysis and P-wave first break identification,
    - P and S-wave relative arrival times,
    - P-S arrival time differences.

  Generally, source location algorithms attempt to minimize iteratively a cost function identified as the RMS difference between the three fundamental parameters and corresponding synthetic derived values. The derivation of synthetic values is referred to as forward modeling, and this requires the specification of the velocity structure of the area under investigation.

  The previously described parameters do not require that the event start time t_0 be known. Only the relative arrival times and the source full waveforms (for the case of polarization analysis) are required; therefore, it is not required to capture the seismic data from start time t_0 to the times required to travel to the PSM seismic sensors. It is only required that sufficient sampling time is specified so that the source waves are captured at all the installed PSM seismic sensors.

  For a first estimate of the required Sampling Time, the user should determine the maximum travel time (t_{MAX}) of a S-wave propagating between two maximally spaced seismic sensors (d_{MAX}) and assuming a S-wave velocity equivalent to the *in-situ* RMS value (VS_{RMS}) (ie., $t_{MAX} = d_{MAX} / VS_{RMS}$). To determine the recommended Sampling Time the user should add to the travel time at least 100 ms to cover six periods of a 60Hz SH source wave. In addition, a margin of 25% should be included to account for pre-trigger data. For example, if t_{MAX} is calculated to be 600ms then the Sampling Time is defined as

  $$\textit{Sampling Time} = 1.25 \text{ x } (t_{MAX} + 100) = 875 \text{ ms}$$

Since data storage is not really limited in most cases, it is more important that the Sampling Time is set large enough to capture all required data for the PSM system than to optimize this parameter.

- **<u>Sensor Sensitivity</u>** - the seismic sensor's sensitivity allowing for the recording of the particle accelerations or velocities (in the true units of m/s^2 or m/s respectively) is provided by your PSM system supplier.

3.2 Common Trigger Parameters

The *Common Trigger Parameters* tab is shown in Figure 4 and the fifteen input parameters required on this tab are as follows:

- **<u>Automated STA/LTA Window Settings Enabled Checkbox</u>** - the event detection portion of the ***µSeis-DAC™*** program is based upon the Short Term Average to Long Term Average (STA/LTA) ratio of the filtered seismic data. An "event" then occurs whenever this ratio exceeds a user defined threshold for the particular sensor under analysis. If the *Automated STA/LTA Window Settings Enabled* Checkbox is checked then the STA and LTA window lengths are set automatically.

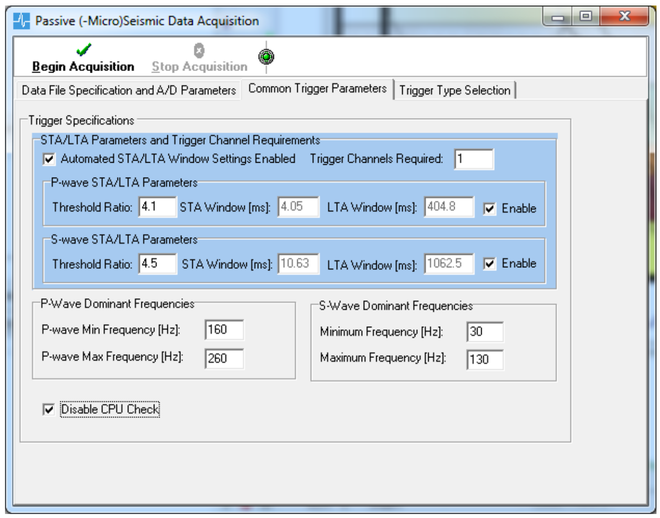


Figure 4: Common Trigger Parameters Screen

- **<u>Trigger Channels Required</u>** – the trigger channels required parameter defines how many sensor channels must see an "event" for it to be identified as an overall PSM event.
- **<u>P- or S wave STA/LTA Parameters</u>**
  The ***µSeis-DAC™*** program allows for the P-wave and the S-wave trigger to be enabled with differing STA/LTA parameters specified. For each wave type the following parameters must be defined:
  - **<u>Threshold Ratio</u>** – the threshold for the STA/LTA ratio for the P- or S-wave under analysis
  - **<u>STA Window</u>** – STA Window length specified in ms for the P- or S-wave under analysis. If the *Automated STA/LTA Window Settings Enabled* Checkbox is checked then this value is specified automatically.
  - **<u>LTA Window[ms]</u>** – LTA Window length specified in ms for the P-wave under analysis. If the *Automated STA/LTA Window Settings Enabled* Checkbox is checked then this value is specified automatically.
  - **<u>Enabled</u>** – If this check box is checked then the P- or S-wave STA/LTA event detection is enabled.

- <u>**P- or S- wave Dominant Frequencies**</u>
  The dominant frequencies input parameters allow the investigator to specify minimum (f^P_{min} *or* f^S_{min}) and maximum (f^P_{max} *or* f^S_{max}) expected values for the P- or S-wave dominant frequency. These values are utilized within the Automated STA/LTA Window Settings when calculating the STA and LTA window length calculation: the STA time window is defined to be 85% of the median period ($STA = 0.85 \times (2/(f^*_{min} + f^*_{max}))$), while the LTA time window is defined as 100 times the STA time window ($LTA = 100 \times STA$).
  - <u>**Min Frequency**</u> – minimum P- or S-wave dominant frequency (f^*_{min}) in Hz. The f_{min} value defaults to 160 Hz and 30 Hz for P- and S-waves respectively.
  - <u>**Max Frequency**</u> – maximum P- or S-wave dominant frequency (f^*_{max}) in Hz. The f_{max} value defaults to 260 Hz and 130 Hz for P- and S-waves respectively.

  It should be noted that the event detection portion of the ***SEED™*** algorithm also requires that the estimated dominant frequency resides within the previously described P-wave and S-wave frequency windows.
- <u>**Disable CPU Check**</u> – As outlined in section 3.1, if the computer cannot maintain the specified sampling rate for the configured number of channels the error message "'Insufficient CPU speed for Triggering Algorithm!" is displayed and the user is exited out of data acquisition. The user can disable the CPU timing check by checking the *Disable CPU Check* box. When timing issues arise with this box checked, a file is saved as outlined in *Data File Specification* but in this case with the string "CPUFailure" appended. For example, the file uSEIS_25_05_2011 11_51_26_053.aci becomes uSEIS_25_05_2011 11_51_26_053CPUFAILURE. The only information saved within "CPUFailure" is the trigger processing time in ms.
  There may be occasional instances when the CPU trigger timing is exceeded (e.g., opening an application) and the user does not want to exit out of the PSM data acquisition. In this case the user only wishes to be notified of the time when this occurred and the corresponding trigger processing time. The *Disable CPU Check* facilitates this.

3.3 Trigger Type Selection

The *Trigger Type Selection* tab is illustrated in Figure 5 where the user must specify the desired Trigger Type and the associated signal processing filter parameters. There are three trigger types: Contact, Frequency Filter, and SEED™:

- ***<u>Contact trigger</u>***
  The *Contact* trigger is equivalent to an electronic switch, which triggers when no signal processing is done and STA/LTA event detection is

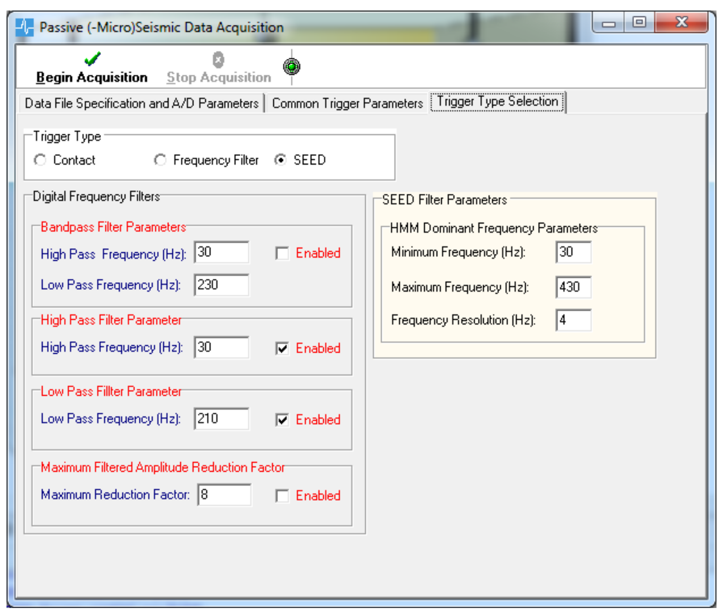


Figure 5: Trigger Type Selection

applied to the seismic time series data. An example of a Contact trigger is the SH hammer beam trigger where a trigger occurs when contact is made between source and receiver (e.g., when the source hammer strikes the truck pads). The *Frequency Filter* trigger allows for the application of digital frequency filters to the recorded seismic data prior to the STA/LTA event detection, while the SEED trigger enables the application of the ***SEED™*** algorithm with STA/LTA event detection.

- ***Frequency Filter* trigger**
  For the *Frequency Filter* trigger the ***µSeis-DAC™*** program offers three digital zero-phase shift frequency filters (Bandpass, High Pass, and Low Pass) as well as the parameter *Maximum Filtered Amplitude Reduction Factor:.*
  - ***Bandpass Filter***
    1) **High Pass Frequency** – lower cut-off frequency in Hertz. Frequencies below this value are removed from the seismic data. The high pass frequency value defaults to 30 Hz.
    2) **Low Pass Frequency**– higher cut-off frequency in Hertz. Frequencies above this value are removed from the seismic data. The low pass frequency value defaults to 210 Hz.
    3) **Enabled** – If this check box is checked then the Bandpass filter is enabled. The Bandpass filter is not allowed to be enabled if either the High Pass or Low Pass filters have been enabled.
  - ***High Pass Filter***
    1) **High Pass Frequency** – lower cut-off frequency in Hertz. Frequencies below this value are removed from the seismic data. The high pass frequency value defaults to 30 Hz.
    2) **Enabled** – If this check box is checked then the High Pass filter is enabled. The High Pass filter is not allowed to be enabled if the Bandpass filter has been enabled.
  - ***Low Pass Filter***
    1) **Low Pass Frequency** – higher cut-off frequency in Hertz. Frequencies above this value are removed from the seismic data. The low pass frequency value defaults to 210 Hz.
    2) **Enabled** – If this check box is checked then the Low Pass filter is enabled. The Low Pass filter is not allowed to be enabled if the Bandpass filter has been enabled.
  - ***Maximum Filtered Amplitude Reduction Factor***
    The STA/LTA event detection algorithm is dependent upon relative amplitudes values (ratio calculation); therefore, there is no indication to what extent the amplitudes have been decreased by applying the frequency filters. Therefore it is possible that noise or filter anomalies of very low magnitude (relative to unfiltered seismic data) are present after frequency filtering, due to the fact that the frequencies intended for isolation were either not present or negligible within the unfiltered seismic data. To address this, the Maximum Filtered Amplitude Reduction Factor provides an additional level of event detection: if the ratio between the Maximum Amplitude Unfiltered Signal / Maximum Amplitude

Filtered Signal exceeds this factor then it is assumed that no "event" has occurred. The factor defaults to 8 within the ***μSeis-DAC™*** program.

- ***SEED™* trigger**
  For the *SEED™* trigger the program requires three input parameters: the minimum (f_{MIN}) and maximum (f_{MAX}) sinusoidal dominant frequencies as well as the frequency resolution (f_R):
  - **Minimum Frequency** – minimum HMM dominant sinusoidal frequency in Hz. The f_{MIN} value defaults to 30 Hz within the ***μSeis-DAC™*** program.
  - **Maximum Frequency** – maximum HMM dominant sinusoidal frequency in Hz. The f_{MAX} value defaults to 430 Hz within the ***μSeis-DAC™*** program.
  - **Frequency Resolution [Hz]** – The HMM frequency resolution. The f_R value defaults to 4 Hz within the *μSeis-DAC™* program.

3.4 Begin Acquisition and Stop Acquisition Tool Bar

Once the user has specified the desired Trigger Type and the associated input data, PSM can commence. The ***μSeis-DAC™*** tool bar options are as follows:

- **Begin Acquisition** - the *Begin Acquisition* option is chosen once the Trigger Type and the associated data acquisition and filter parameters have been specified. ***μSeis-DAC™*** stores the user specified data acquisition and filter parameters in the *useisDAC.ini* file and these values become the default parameters. Once the *Begin Acquisition* button has been selected ***μSeis-DAC™*** will start the continuous monitoring of the PSM sensors at the user specified sampling rate, and whenever an "event" has been identified the seismic data for all sensors within the PSM network are saved to file in ASCII format.

  The saved seismic data has the following header information:

  sample rate in ms, estimated G-M variance (σ^2), estimated G-M time constant in ms (Tc)), estimated source wave dominant frequency in Hz, number of sensor packages, and sensor channel that triggered the system.

  Note:
  When applying the *SEED™* trigger the background noise is modeled as a stationary Gauss-Markov (G-M) process, which can be defined by its autocorrelation with the two parameters of variance, σ^2, and time constant, T_c. These parameters are derived from the seismic time series in real-time by windowing on the noise portion of the trace and calculating the autocorrelation of the background noise.
  In case of a Contact and Frequency Filter trigger numeric values of -99 are inserted for σ^2, T_c, and the estimated source wave dominant frequency, as these parameters are not available when these triggers are used.

The seismic time series data follows the header information. The seismic data is saved for each sensor sequentially assuming a triaxial configuration. If only a uniaxial or bi-axial configuration exist then a zero amplitude is stored for the missing component. For example, assume there are four channels within a PSM network, and that the first sensor package is triaxial, the second is uniaxial, the third is bi-axial, and the fourth is triaxial. The PSM seismic data is then stored as follows (for t_n of data):

$$x^1_{t1}, y^1_{t1}, z^1_{t1}, x^2_{t1}, 0{,}0, x^3_{t1}, y^3_{t1}, 0, x^4_{t1}, y^4_{t1}, z^4_{t1},$$
$$x^1_{t2}, y^1_{t2}, z^1_{t2}, x^2_{t2}, 0{,}0, x^3_{t2}, y^3_{t2}, 0, x^4_{t2}, y^4_{t2}, z^4_{t2}, \cdots t = t_n$$

- **Stop Acquisition** - the user may abort the operation by pressing the *Stop Acquisition* push button.

On the top right hand corner of the screen a graphical LED shows at all times the status:

Green - ready to commence data acquisition
Yellow - waiting for trigger
Red event occurred

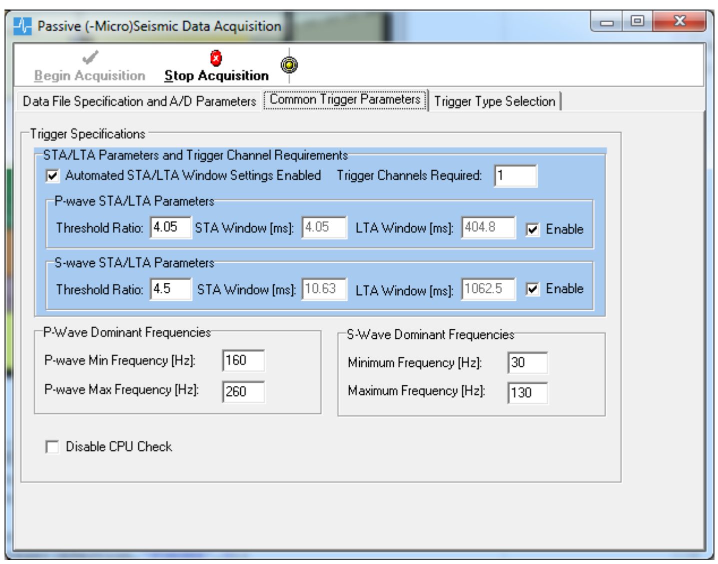


Figure 6: Screen shot while data acquisition is ongoing

Chapter 4 Utilities

The *Utilities* option on the ***µSeis-DAC™*** main menu option contains six sub-menu options (as is shown in Figure 7):

- *Convert to BCE ASCII Format*
- *Convert to SEG2 Format*
- *Default GUI Settings*
- *Sensor Type and Units*
- *View Seismic Data*
- *X-Y-Z Full Waveform Display*

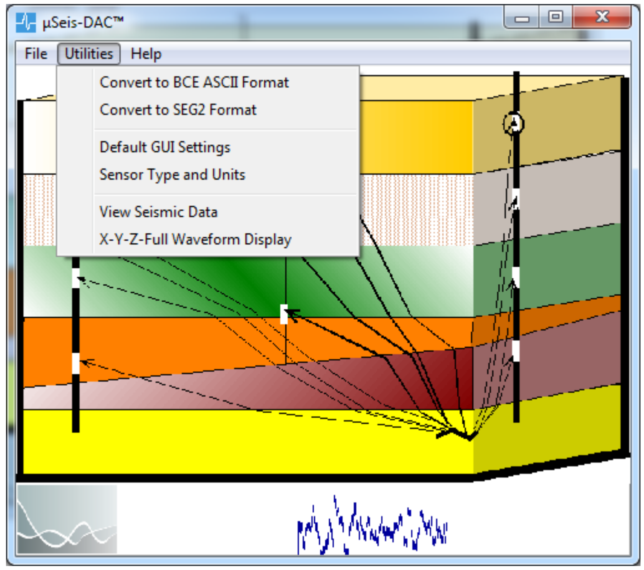


Figure 7: Utilities Sub-Menu Options

4.1 Convert to BCE ASCII Format

The *Convert to BCE ASCII Format* option allows for the conversion of the saved seismic time series data into the BCE standard triaxial format. This conversion is required prior to the implementation of Utilities View Seismic Data and X-Y-Z Full Waveform Display.

When menu option *Convert to BCE ASCII Format* is selected the file input dialog box shown in Figure 8 appears. Here the user can select the desired PSM data file or data files (i.e., <SHIFT> plus left mouse click or <CTRL> plus left mouse click) to convert. The user then selects the *Open* button.

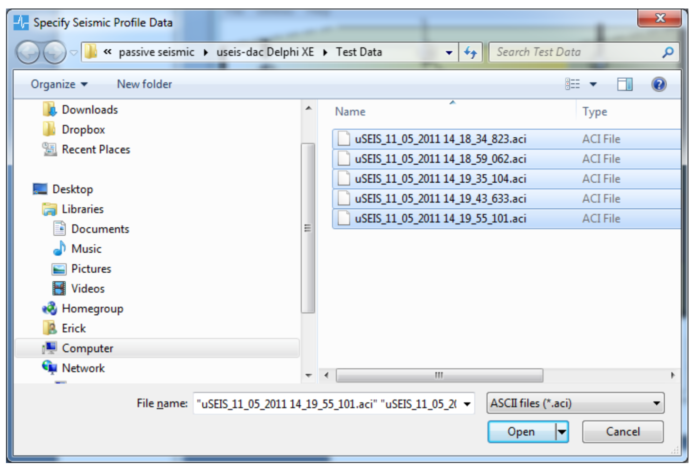


Figure 8: PSM file input dialog box

µSeis-DAC™ automatically creates file subdirectory BCE ASCII where the converted files are saved. The converted files are similarly named as the PSM file to be converted with the exception that the sensor triaxial package number is inserted after the time stamp. For example, PSM file uSEIS_11_05_2011 14_18_34_823.aci (containing four triaxial sensor packages) is converted to the following four triaxial ASCII files:

uSEIS_11_05_2011_14_18_34_823_SENSOR1.aci
uSEIS_11_05_2011_14_18_34_823_SENSOR2.aci
uSEIS_11_05_2011_14_18_34_823_SENSOR3.aci
uSEIS_11_05_2011_14_18_34_823_SENSOR4.aci

4.2 Convert to SEG2 Format

The *Convert to SEG2 Format* option allows for the conversion of the saved seismic time series data into a user specified and customized SEG2 seismic data format. This option allows the ***µSeis-DAC™*** user to process the acquired PSM data files with a variety of PSM analysis software packages.

When menu option *Convert to SEG2 Format* is selected the file input dialog box shown in Figure 8 appears. Here the user can select the desired PSM data file or data files (i.e., <SHIFT> plus left mouse click or <CTRL> plus left mouse click) to convert. The user then selects the *Open* button.

µSeis-DAC™ automatically creates file subdirectory SEG2 where the converted files are saved. The converted files are similarly named as the PSM ASCII file to be converted with the exception that the extension aci has been replaced with seg. For example, PSM file uSEIS_11_05_2011 14_18_34_823.aci is converted to uSEIS_11_05_2011 14_18_34_823.seg.

4.3 Default GUI Settings

The *Default GUI Settings* dialog box is shown in Figure 9. Here the user can specify the minimum and maximum value for the frequency axis, as well as the precision, the number of digits and the increment for both the vertical amplitude axis and the horizontal time axis.

The minimum and maximum values for the frequency axis are used for the *Utilities->View Seismic Data* frequency display. The default settings for these frequencies are zero and the Nyquist frequency (1/2Δ, where Δ is the sampling rate) respectively. If the user wishes to change these values, then check box *Enable* should be checked and the appropriate minimum and maximum frequencies should be specified.

The precision, the number of digits and the increment for both the vertical amplitude axis and the horizontal time axis are used for the *Utilities->View Seismic Data* and *Utilities->X-Y-Z Full Waveform Display* chart displays. The default settings for these parameters are 6, 3 and 0.01 for the vertical amplitude axis and 4, 2 and 0.01 for the horizontal time axis.

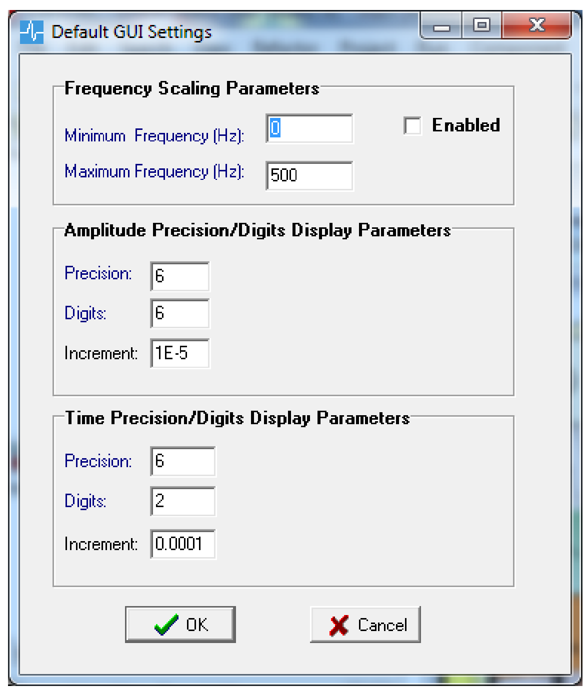


Figure 9: Default GUI Settings

These settings are then stored within configuration file *useisDac.ini* so that they will be implemented whenever *µSeis-DAC™* is used.

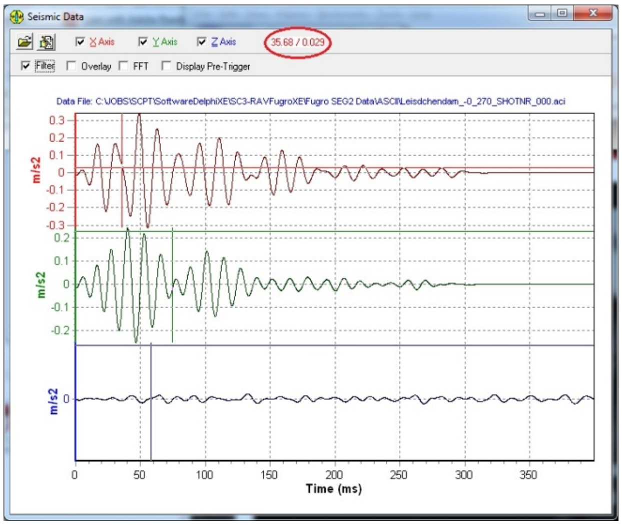


Figure 10: Utilities->View Seismic Data display with the Amplitude and Time default settings (Precision, Digits and Increment) set at 6, 3, 0.01 and 4, 2, 0.1, respectively

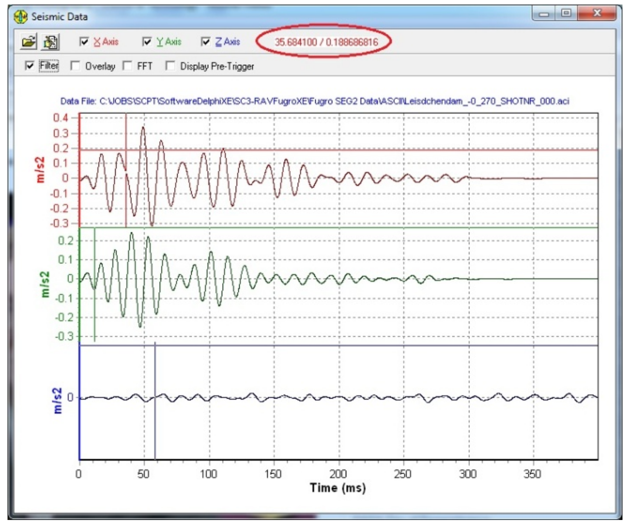


Figure 11: Utilities->View Seismic Data display with the Amplitude and Time default settings (Precision, Digits and Increment) set at 9, 9, 0.00001 and 6, 6, 0.00001, respectively

4.4 Sensor Type and Units

The *Sensor Type and Units* dialog boxes are shown in Figure 12. The *Sensor Type Specification* interface allows the user to specify whether *Accelerometers* (output proportional to particle acceleration) or *Geophones* (output proportional to particle velocity) are used within the PSM network. The *Desired Units* user interface facilitates the specification of whether the particle velocities and accelerations recorded are given in units of m/s and m/s^2 or m/s and mm/s^2, respectively.

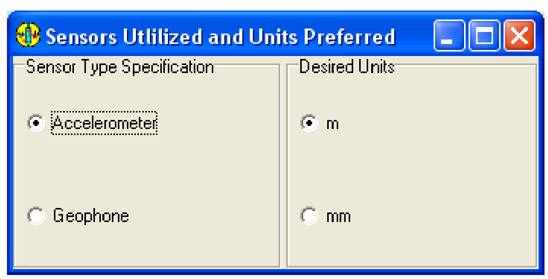


Figure 12: Sensor Type and Units dialog boxes

4.5 View Seismic Data

The *Utilities->View Seismic Data* option allows the user to analyze a BCE ASCII Format triaxial data acquisition file. The analysis features consists of filtering the seismic trace, overlaying the unfiltered trace onto the filtered trace and displaying the smoothed Fourier transform of either the unfiltered or filtered seismic time series.

Upon selecting this option an input dialog box appears where the user specifies the seismic file to be processed. Figure 13 then shows the graphical output that appears once a seismic file has been selected. At the top of this figure there are three checkboxes (*Filter*, *Overlay,* and *FFT),* and the numeric values of the time and amplitude at the current location of the graphical crosshair.

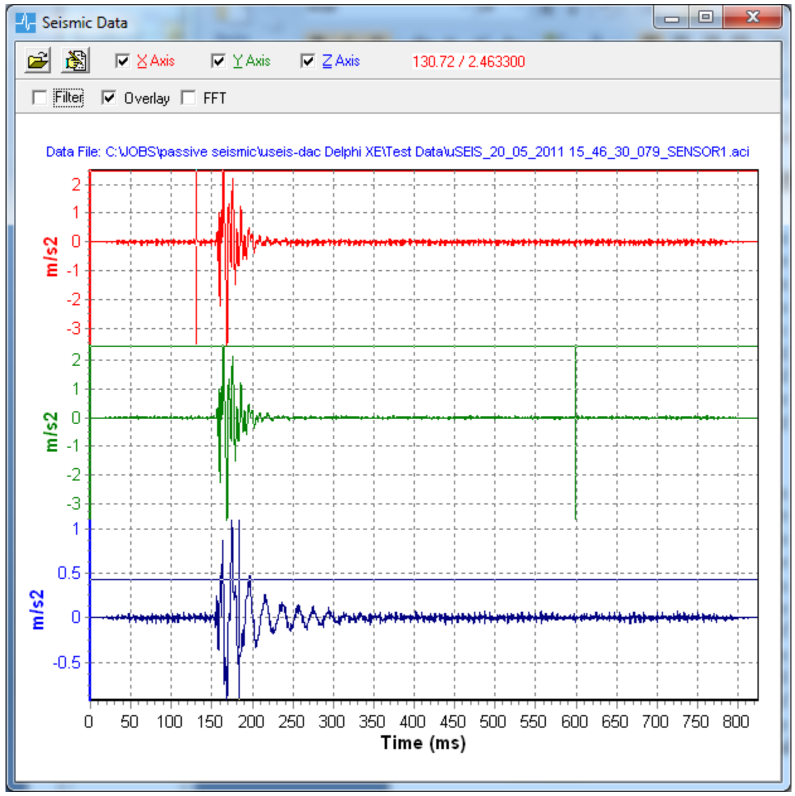


Figure 13: Main graphical interface in Utilities->View Seismic Data software option

If the *Filter* check box is selected the graphical output shown in Figure 14 appears, which shows the graphical results after specifying a bandpass of 30 to 200 Hz. The user may then overlay the unfiltered seismic trace onto the filtered trace by selecting checkbox *Overlay* as illustrated in Figure 15. The smoothed Fast Fourier Transform (FFT) of either the unfiltered or filtered seismic trace is derived and displayed by selecting checkbox *FFT*. The frequency spectrum of the filtered trace is displayed if the checkbox *Filter* is selected along with the *FFT* checkbox. Otherwise the unfiltered seismic trace's frequency spectrum is displayed. Figure 16 shows the frequency spectrum of the unfiltered data file shown in Figure 13.

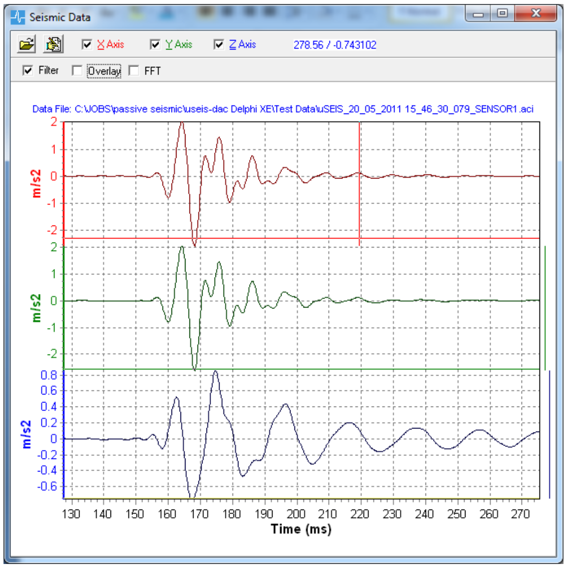


Figure 14: Filtered seismic trace in Utilities->View Seismic Data software option

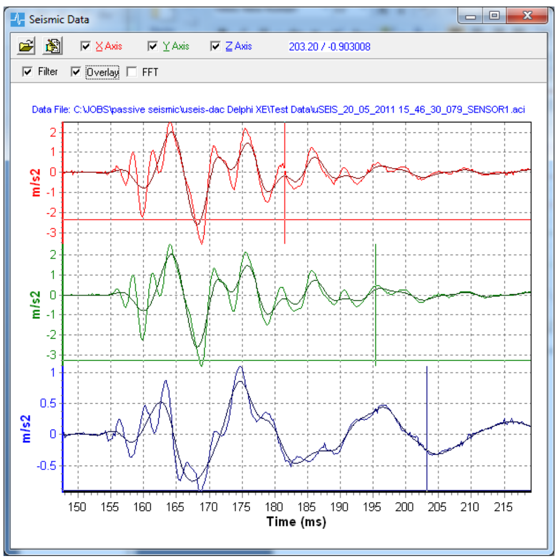


Figure 15: Overlaying unfiltered seismic time series onto filtered time series

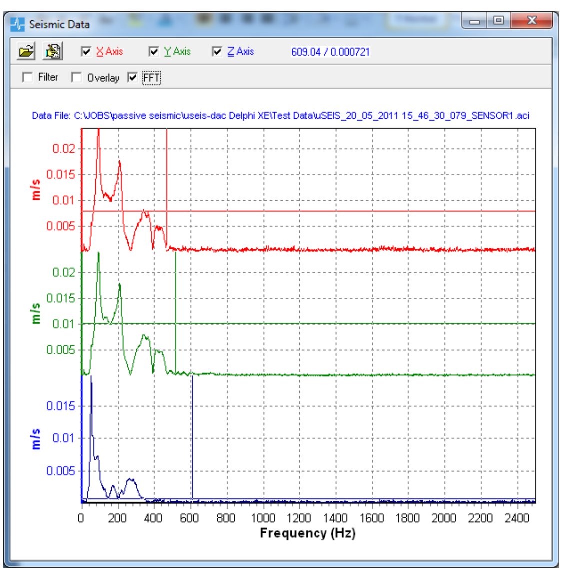


Figure 16: Display of frequency spectrum of seismic time series illustrated in Figure 13

4.6 X-Y-Z Full Waveform Display

The *X-Y-Z Full Waveform Display* option allows the user to analyze multiple BCE ASCII Formatted triaxial data acquisition files. When the user selects the *Utilities→ X-Y-Z Full Waveform Display* option, the file input dialogue box shown in Figure 17 appears. The user can input multiple seismic files in this dialogue box (i.e., <SHIFT> plus left mouse click or <CTRL> plus left mouse click). After the *Open* button has been selected by the user, the main *X-Y-Z Full Waveform Display* graphical user interface dialogue box appears as is illustrated in Figure 18. In addition, the selected multiple BCE ASCII Formatted triaxial data acquisition files appear as is illustrated in Figure 19.

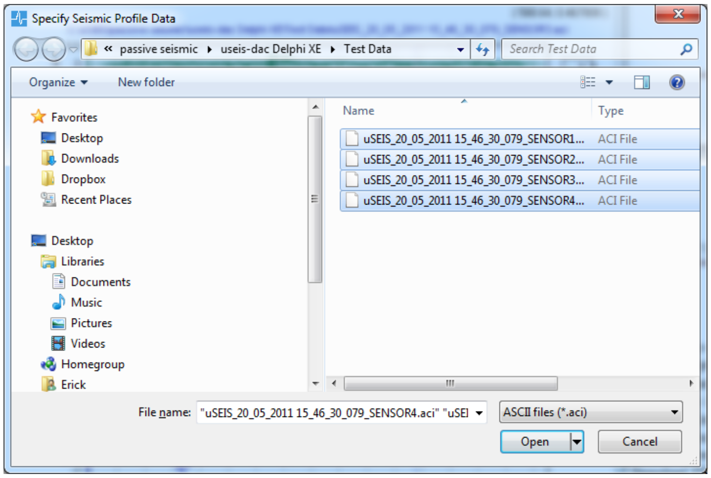


Figure 17: X-Y-Z Full Waveform Display dialog box

The graphical interface box provides two chart display options (to display or not) by selecting the appropriate option for each axis and the full waveform.

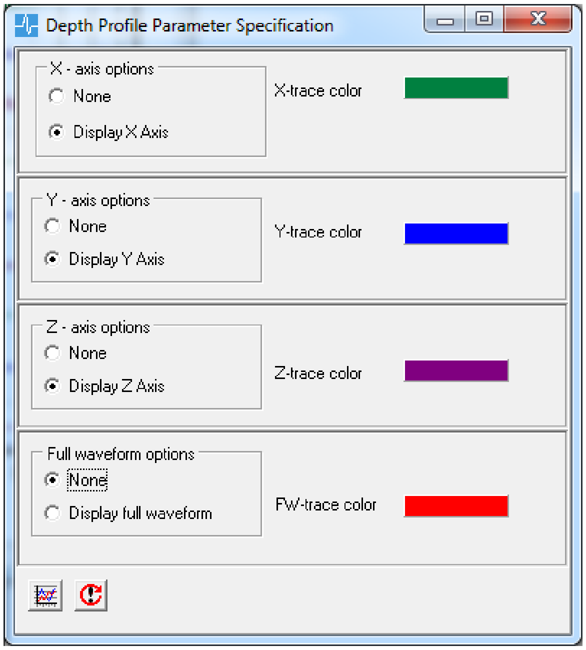
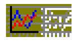


Figure 18: X-Y-Z Full Waveform graphical interface box

The absolute value of the full waveform is displayed and defined as

$$\rho(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2}$$

The user can modify the seismic trace coloring scheme by selecting the appropriate color button. The coloring scheme is then saved within the *useisDAC.ini* file for future applications.

The user should select user button  in order to implement newly specified chart configuration parameters. Selection of user interface button  results in the display of the *Cascadable Filters* dialog box (see Figure 20), allowing the user to specify the filter parameters for the selected filter (i.e. bandpass, notch, high pass or low pass).

The user can normalize the display *locally* or *globally* by opening the *Normalize* pull down menu and then selecting the appropriate normalization option. By normalizing the seismic data *locally*, the amplitudes of a X-component, Y-component, Z-component and full waveform set of time series data for a specific sensor package are normalized with respect to the absolute maximum value recorded for this set of triaxial data. When normalizing the data *globally*, all of the displayed seismic data is normalized with respect to the absolute maximum amplitude recorded within the entire set of displayed data. Figure 21 illustrates the seismic data shown in Figure 19 following a global normalization.

As the user moves the cursor over individual traces, the corresponding file name of the seismic trace is displayed at the top center of the chart. The user can display acceleration, velocity or displacement profiles by pressing the right mouse button and selecting the desired particle motion. The user can display peak particle values for acceleration (PPA), velocity (PPV) and displacement (PPD) within the *X-Y-Z-Full Waveform* display by selecting button Show PP as illustrated in Figure 22.

A new set of data files can be read in by selecting user interface button Read data . The graphical edit button  allows for extensive chart editing as outlined in Chapter 5. The *Save* and *Load* buttons allow the user to save and to load configured chart edit settings, respectively

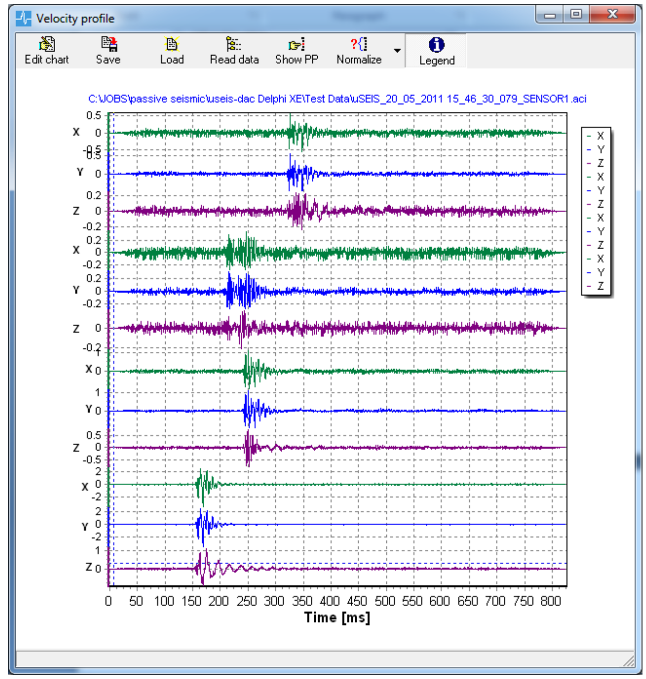


Figure 19: Example of X-Y-Z-Full waveform output where the X-component, Y-component, Z-component, and full waveform seismic time series data is displayed

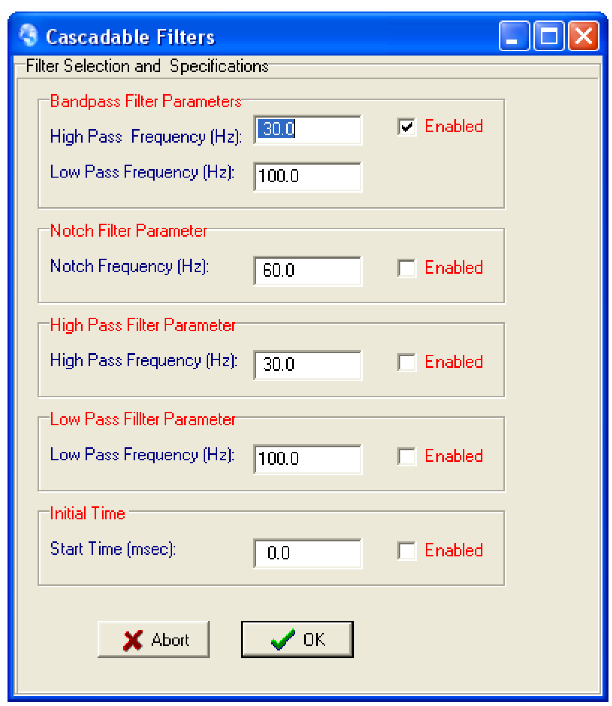


Figure 20: Cascadable Filters User Interface

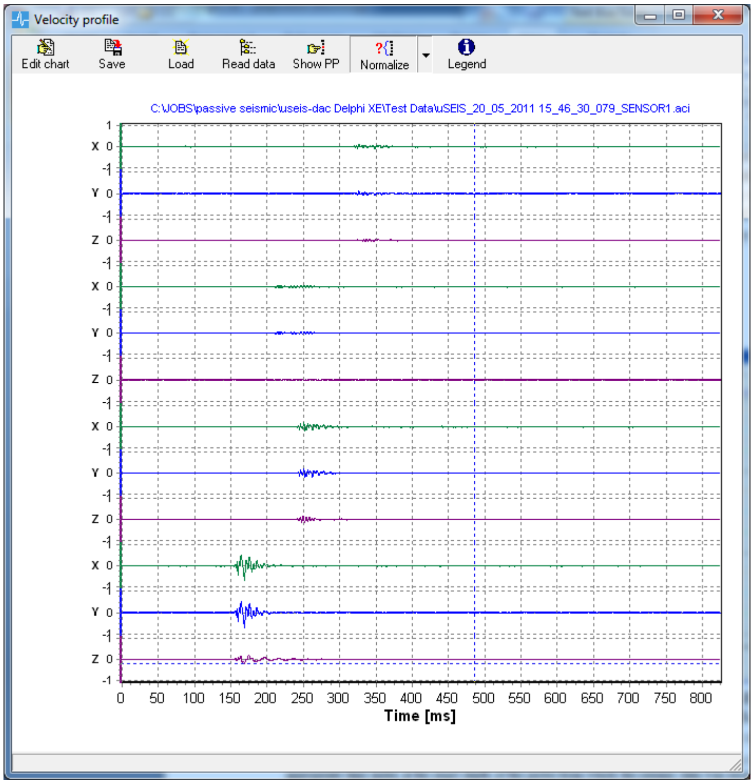


Figure 21: Seismic Time Series Data Shown in Figure 19 with the Globally Normalization Option Enabled

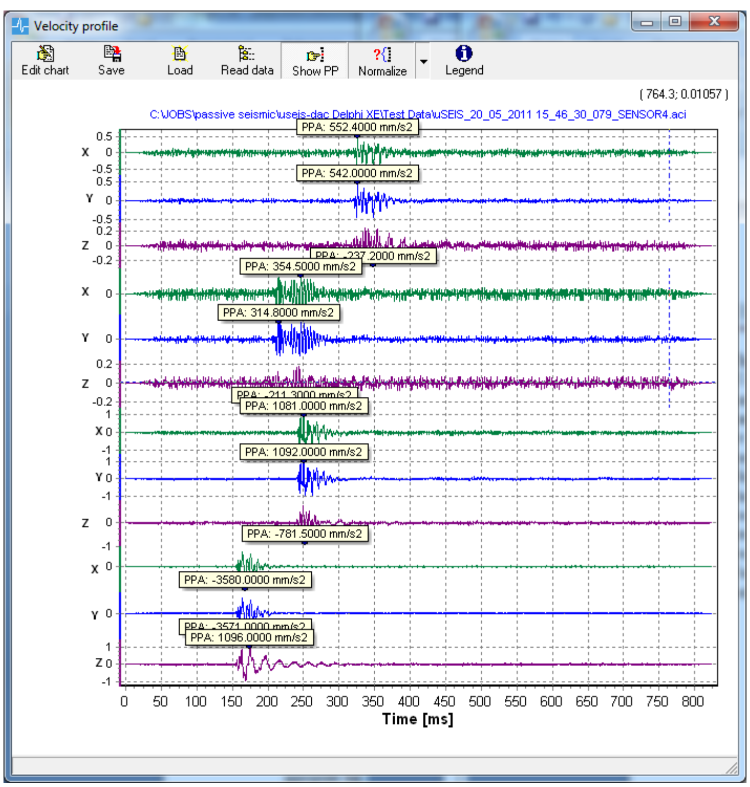


Figure 22: Display of PPA by selecting button Show PP.

Chapter 5 Chart Formatting, Exporting, and Printing

The graphical edit button  displayed at the top left hand corner of the *View Seismic Data* and *X-Y-Z Full Waveform Display* screens shown in the previous figures allows for chart formatting, printing, and exporting. Figure 23 illustrates the graphical interface that appears when this button is selected, which allows for extensive modification of the displayed data and chart attributes. In addition the data can be printed by selecting the *Print* tab, which brings up the *Chart Printing Dialog Box* as shown in Figure 24. Finally, this utility has an extensive electronic Help function, which is accessed though the H*elp* button at the bottom left of the screen.

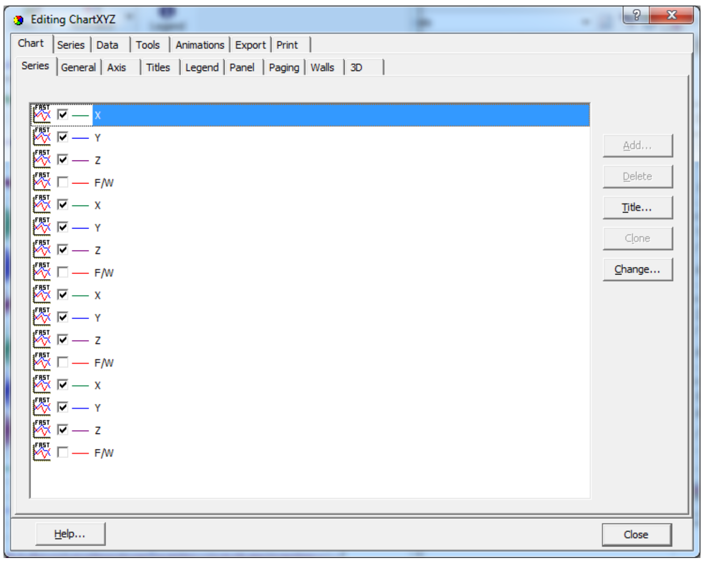


Figure 23: Chart Editing Dialog Box

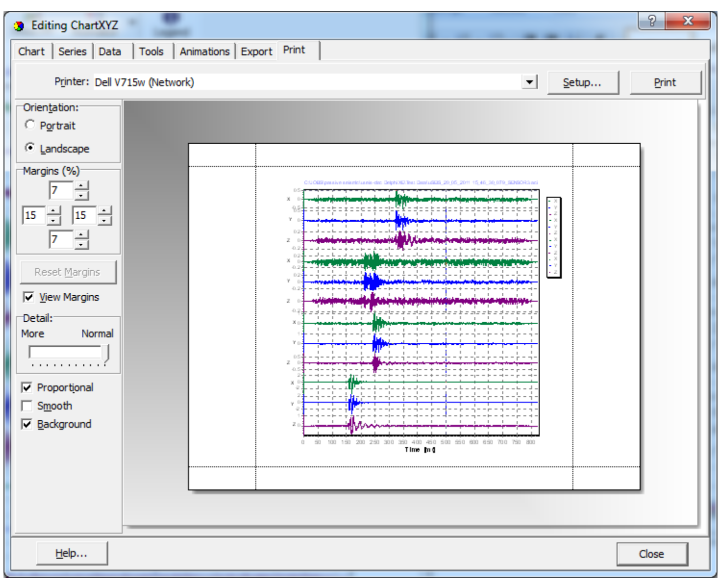


Figure 24: Chart Printing Dialog Box

Chapter 6 Help Menu

The main menu shown in Figure 1 includes a *Help* option that includes the following:

- **About** - provides software version information on ***µSeis-DAC™***.
- **User's Manual** - will output the ***µSeis-DAC™*** user's manual in a default pdf browser.
- **Link to BCE** - makes a link to *Baziw Consulting Engineers'* web page.

Appendix 1 Baziw, E.. 2005. Real-Time Seismic Signal Enhancement Utilizing a Hybrid Rao-Blackwellised Particle Filter and Hidden Markov Model Filter. IEEE Geosci. Remote Sensing Letters (GRSL), vol. 2, no. 4, pp. 418-422.

Appendix 2 BCE technical note entitled "Passive (Micro-) Seismic Event Detection by identifying, quantifying and extracting frequency anomalies within statistically describable background noise".

Appendix 3 BCE technical note entitled "Relating Peak Particle Velocity and Acceleration to Moment Magnitude in Passive (Micro-) Seismic Monitoring".

Appendix 4 µSeis-DAC™ Installation Procedure

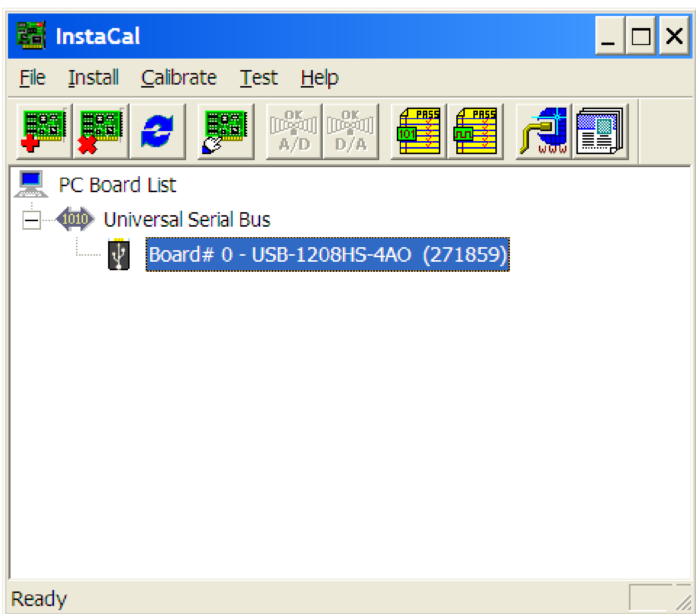
In order for *µSeis-DAC™* to function properly it is important that the all software (incl. the *InstaCal* software) is installed in the right sequence. Therefore do not connect the USB-1208, 1408, or 1608HS A/D device (12 bit, 14 bit and 16 bit, respectively) until step 3.

The software should be installed as follows:

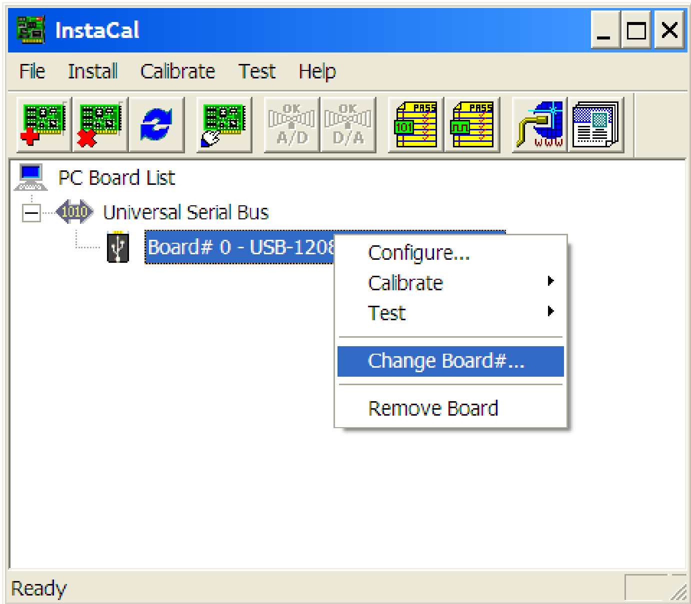
1. Put ***µSeis-DAC™*** CD into CD reader; navigate to sub-directory *InstaCal 6.01* and install *InstaCal* (select file *icalsetup.exe*).

2. After installation, reboot the computer.

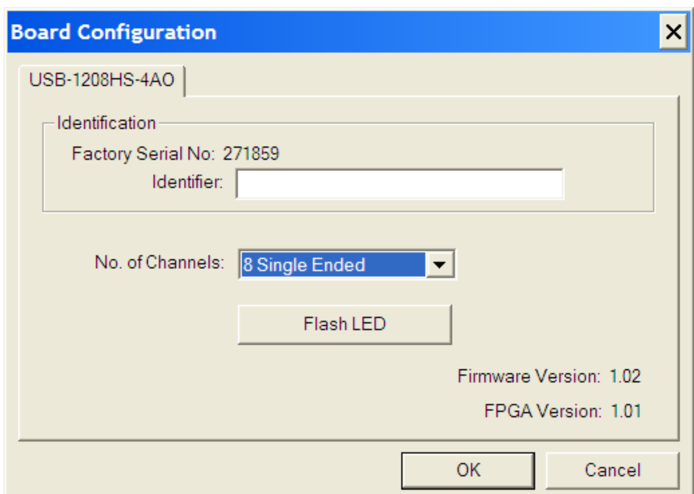
3. Plug USB-**08HS A/D into USB port and execute program *InstaCal*. *InstaCal* insures that the USB A/D device is recognized by the Windows® operating system and allows for configuration and calibration. Verify that the USB-**08HS device is configured as Board #0 as illustrated below.



If not, select the USB-**08HS A/D device and right mouse click and select the *Change Board #* as shown below.



4. Configure the USB-**08HS A/D device as *Single Ended* by selecting the *Configure* option shown above and selecting *8 Single Ended* as illustrated below.



5. Put ***µSeis-DAC™*** CD into CD reader; navigate to sub-directory *SC3-DAC Pro.* Execute program *setup.exe*.

6. ***µSeis-DAC™*** default directory is c:\USEIS-DAC unless otherwise specified.

7. Execute program c:\USEIS-DAC\USEISDAC.exe.